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Contamination Assessment of Dumpsites in Ughelli, Nigeria using the Leachate Pollution Index method

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ABSTRACT: The leachate pollution index (LPI) technique has been used to quantify pollution potential in Ughelli, Nigeria. Water samples were collected from boreholes around four dumpsites for laboratory analysis and estimation of their LPI. The values were found to be 11.95, 11.32, 8.47 and 10.08, for Omotor Dumpsite (OD), Iwhreko Dumpsite (ID), Divine Dumpsite (DD) and Ughelli Market Dumpsite (UMD) respectively. These values are higher than the standard of 7.378. Therefore, Leachate characterization and the LPI values revealed that the groundwater in the area has been impacted due to leachate percolation. It is recommended that remediation procedures should be put in place as soon as possible for better water quality in the area. ©JASEM
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Keywords: Pollution index; remediation; biodegradation; water quality; hydrogeochemical analysis, pollutant variables

The fundamental uses of water which is an essential ingredient for plant, animals, and human beings for domestic and industrial purposes cannot be overemphasized. Thus water supplies from boreholes must be between the recommended limit of Leachate pollution index (LPI) for human use in order to be free from contaminants capable of threatening human, plants and livestock lives. In recent times, indiscriminate drilling of laterite sand for road and building construction has become the order of the day. These various drilled sites are now land fill area which consist of municipal or borough sources of waste.

Over half a decade, wastes are deposited in landfill area without considering both its effects on the environment and humans. In Nigeria, wastes disposal in these area is assumed to be economical, easy and the cheap when compared to incineration method (Mohammad *et al*, 2010; Susu and Salami, 2011; Mohajeri *et al*, 2010).

Poor management of municipal solid waste in Nigeria, Ughelli in particular has resulted in unprecedented environmental, bionomical and human health problems. These problems, most especially the impact on groundwater quality has become a major concern for the people of Ughelli, Nigeria (Egbai, *et al*. 2013). Also, with an increasing rate of urbanization in the area, indiscriminate citing of boreholes at proximity to dumpsite has facilitated the infiltration of lethal waste to aquifer region of subsurface water (Pandey and Tiwari, 2009).

Nowadays, there are buildings surrounding several landfills and these are potential sources of contaminants thus causing a principal threat to groundwater aquifer (USEPA,1984; Fatta *et al*, 1999). The leachate pollution strength depends on the nature, and the amount of toxicity of the waste in the leachate liquid, aquifer depth, formation strata, groundwater flow direction etc (Al-Khaldi, 2006), and the precipitation of municipal solid waste (leachate) into groundwater (Lee and Jones-Lee, 2004). Also when wastes are dumped close to water bodies (rivers,streams, lakes), they float in the water, some sink while others are soluble to form leachate that percolates to aquifer thus contaminating both the water bodies and aquifer system(Lee and Jones-Lee, 2004). Some of the determinant factors that influence the formation of leachate include the categories of wastes dumped in the landfill, the degree of compression, landfill age, the weather and climate of the landfill area, particle size, the site hydrology and the type of landfill design (Rafizul*et al*, 2011; Leckie *et al*, 1979; Kouzeli-Katsiri *et al*, 1999). Several cases had been reported about leachate pollution of both subsurface water and aquifer system(Ofomola, 2016; Salami *et al*, 2015; Barjinder -Bhalla *et al*, 2014; Kumar *et al*, 2002; Chain and DeWalle, 1976; Kelley, 1976; Reinhart and Grosh, 1994).

Leachate Pollution Index (LPI) was developed in an attempt to initiate a method for assessing leachate pollution strength (potential) of various landfill waste sites in a given geographical terrain in the world at large. The total potential of the pollution of landfill leachate liquid can be computed in terms of leachate pollution index[LPI] as suggested by Kumar and Alappat (2003). The LPI was formed using Rand Corporation Delphi Technique for estimating the echelon of leachate pollution potentials for landfill sites in a given region. As the LPI value increases, the site is prone to higher threat of contamination, thus indicating poor water quality (Kumar and Alappat, 2003). LPI is a progressively scale index within the

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range of 5 and 100 indicating the overall leachate contamination strength of a landfill with various wastes parameters such as biological oxygen demand(BOD), chemical oxygen demand (COD), cadmium, total dissolved solids (TDS), etc at a given period of time. The standardized value of LPI is 7.37 (Kumar and Alappat, 2003). The LPI helps in singling out and quantifying pollutants in the municipal solid waste(MSW) landfill leachate for ascertaining site(s) for urgent attention and providing remedial and preventive measures over a period of time. LPI uses also include landfills site ranking, trend analysis, type of resources to be allocated for landfill remediation to minimize wastes effects on organisms, specification of groundwater standard quality, scientific research and public enlightenment.

This paper is aimed at evaluating the leachate pollution potential (LPI) of borehole water samples from four waste dumpsites in Ughelli to ascertain water quality, and areas that require remedial measures.

MATERIALS AND METHODS

*Site Description***:** The study area is characteristically underlain by the Niger Delta formations sequence, which comprises of the Benin, Agbada and Akata Formations. Ughelli is directly underlain by the Somebreiro-Warri Deltaic Plain sands, which is the top of the Benin Formation. The geology of the Niger Delta have been studied and well documented by several authors (Allen, 1965; Reyment, 1965; Short and Stauble, 1967; Weber and Daukuro, 1975). Studies show that the Somebreiro - Warri Deltaic Plain sand is Quaternary to Recent has and a thickness of about 120 m (Wigwe 1975). The sediments are unconsolidated in texture and vary from fine plastic clay through medium - coarse grain sand that are sometimes gravelly. Predominantly, the Benin Formation consists of unconsolidated sand, gravel and occasionally intercalation of shale. It is the main source of freshwater in the Niger Delta region and with about 2000 m thick ranging from Oligocene to Pleistocene in age.

The four dumpsites are in Ughelli south area of Delta state (Figure 1), and they include Omotor Dumpsite (OD), Iwhreko Dumpsite(ID), Divine Dumpsite(DD) and Ughelli Market Dumpsite (UMD). Omotor Dumpsite is located at latitude and Longitude of N05^{0} 29.915^{1} and E005^{0} 59.135^{1} respectively with an elevation of ±32 m. ID is located at latitude N05^{0} 29.553^{1} and longitude E005^{0} 59.532^{1} with elevation ±26 m. The third location is the Divine dumpsite with Latitude N05^{0} 29.745^{1} and Longitude E006^{0} 00.171^{1} with elevation of ±31 m. Ughelli Market Dumpsite (UMD) is located at latitude N05^{0} 29.993^{1} and Longitude E005^{0} 59.406^{1} with elevation of ±29 m. The dumpsites are still active, and accept wastes from different sources within the area. The wastes are composed of several materials mainly human and animal waste, organic and inorganic matters, various types of plastic, metal scraps, human and animal faeces, and other unspecified industrial squander (Longe and Balogun, 2010). Base on the biodegradation that the waste undergo, they generate leachate which could be a point source of contaminant into the soil and consequently to the groundwater. Therefore it is pertinent to ascertain the quality of the groundwater from the leachate pollution index.

Leachate Sample Collection: Water samples from four (4 boreholes) locations, one each close to the dumpsites were collected using 1.5 liters plastic containers. Impurities were removed from the plastic containers by soaking it with little quantity of citric acids and thoroughly shaken and rinsed with distilled water in order to prevent contamination and was put to use after the container had dried off. In the respective dumpsites, each of the plastic containers were rinsed with liquid that are to be collected evenly before collection and then sealed. The samples were sealed when filled with water, labeled and stored in an ice block cooler at room temperature to reduce vaporization and deficiency of dissolved gases from the water.

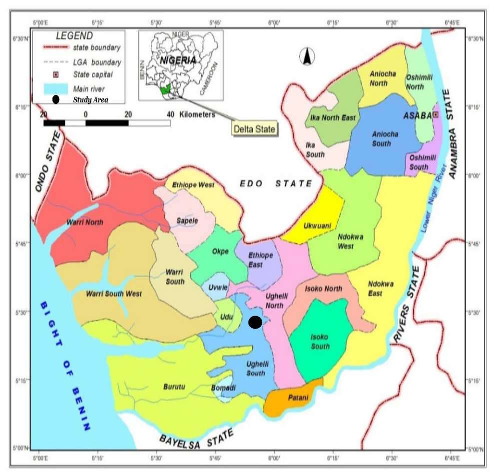

Fig 1: Map of Delta State showing the study area

The samples were taken to the analytical laboratory of Delta State University, Nigeria for quantifications of leachate parameters by using different reagents and analytical apparatus. Leachate parameters were computed according to standard approach for water examination and contaminated water by APHA, (1985) using AA-20 atomic spectrometer. Systematic, random and erratic errors were reduced to the lowest minimal as mean values of experiment were calculated.

Analytical methods: The standard methods for the examination of water and waste water according to

American Public Health Association (APHA, 1985) were employed for the water analysis. The Electrometric method (4500-H^+. B of Standard Method) was used for the pH measurements. The BOD_5 was determined using the Azide Modification Method (5210 A .APHA, 19^{th} Edn. 1995), and for Cyanide, the distillation method was adopted. COD was determined by the titration of refluxed sample with Ferrous Ammonium Sulphate (5220C: Standard Methods). The Argentometric volumetric titration method (4500-Cl-B of Standard methods) provides reliable information on the amount of Chloride. Also, for the heavy metals analysis, the GBC Atomic Absorption Spectrophotometer was used (3030-B, and 3030 -E-K standard methods).

*Calculating LPI:*The LPI (Leachate Pollution Index) is a proficient tool for the assessment of the extent of leachate pollution from dumpsites. It can be adequately applied to areas prone to groundwater contamination as a result of leachate migration. Parameters used for the LPI estimation include pH, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen, Total Iron, Copper, Nickel, Zinc, Lead, Chromium, Mercury, Arsenic, Phenol, Chlorides, Cyanide, and Total Coliform Bacteria.The variable weight factor for these parameters were calculated and this indicates the importance of each pollutant variable to the overall leachate pollution with chromium and total iron having the highest and least weight factor of 0.064, and 0.045 respectively (Fronczyk and Garbulewski, 2009). Also, to determine a relationship between leachate pollution and concentration of parameter, the sub - index curves for all the variables were used (Kumar and Alappat, 2003). The linear aggregation function using the weighted summation method was used for the final calculation of the LPI. Generally, in order to calculate the LPI, the sub-index values for all the parameters were determined from the average sub-index curves of the pollutant variables and the values multiplied with the respective weights assigned to each parameter using equation 1 (Kumar and Alappat, 2003).

$$LPI = \sum_{i=1}^{n} WiPi \qquad 1$$

However, when one or more data for the estimation is not available, the LPI can be calculated using equation 2.

$$LPI = \frac{\sum_{i=1}^{n} WiPi}{\sum Wi} \qquad 2$$

Where W_i = the weight for the i^{th} pollutant variable, P_i = the sub-index value of the i^{th} leachate pollutant variable, n = the number of leachate pollutant parameters for which data is available. In the present study, one parameter was absent and hence equation 2 was applied.

Statistical Analysis: Correlation analysis for leachate parameters is a descriptive technique to determine or assess the degree of association among the various variables. For this study, Statistical package for Social Sciences (SPSS version 19.0) was used. The multivariate statistical analysis employing the Spearman Rank - order correlation was adopted for optimal results and reliable data interpretation for the various LPI parameters.

RESULTS AND DISCUSSION

The hydrogeochemical analysis of the water samples across the dumpsites are shown in tables 1 and 2. The results show that the pH value ranges from 6.60 - 7.10. This is an indication that the leachate is still young (Abbas *et al*, 2009). Also, the low values for TDS ranging from 29.8 - 42.1 mg/l show that the extent of mineralization of the leachate is low. However, the ID has the highest tendency of changing the physico-chemical characteristics of the receiving water more than the others. The BOD and COD range from 1.20 - 2.80 mg/l, and 10.40 - 18.00 mg/l respectively. This indicates the extent of organic pollution in the groundwater emanating from the dumpsites. Also the ratio of BOD/COD is greater than 0.1, and this shows that all the materials in the dumpsites are yet to attain their methanogenic stage (Deng and Englehardt, 2007). The Ammonia - nitrogen concentration varies from 0.95 - 2.09 mg/l, with UMD having the highest. This represents the major content of total nitrogen from the dumpsites and these increases with the age of the dumpsite due to the hydrolysis and fermentation of the biodegradable material with nitrogenous fractions (Abbas *et al*, 2009). It is stable under anaerobic circumstances and therefore considered as a major long-term pollutant, which enhances the development of algae and can also interrupt the operations of biological leachate treatment (Deng and Englehardt, 2007).

The concentration of heavy metals in the dumpsites is fairly low, and this is as a result of decreased pH at later stages in the life of the dumpsites, resulting in a decrease in metal solubility, and thereby leading to a rapid decrease in concentration of heavy metals. In all the dumpsites, chromium ranges from 0.02 - 0.04 mg/l, lead from 0.01 - 0.02 mg/l, zinc from 0.18 - 0.21 mg/l, nickel from 0.00 - 0.09 mg/l and copper from 0.02 - 0.06 mg/l. The concentration of chloride ranges from 7.06 - 11.00 mg/l and according to D'Souza and Somashekar, (2012) chloride cam be used as a strong indicator of contamination since it is inert and non- biodegradable. Therefore, the UMD with the highest chloride level has the greatest likelihood for contamination.

In order to do a comparison of the analysed parameters, the data were compared with the Leachate disposal standard in India since there is no available LPI standard in Nigeria. Comparing the analysed parameters in all dumpsites investigated with the leachate disposal standard, chromium, lead, BOD, COD, arsenic, zinc, TKN, nickel, NH_3-N, TDS, copper and chloride, are below standard. The pH values for all the dumpsites are within the stipulated standard according to APHA,(1998). For cyanide, ID and DD are below the stipulated standard, while UMD is within the stipulated standard and OD was found to be above the stipulated standard. For phenol, location OD and ID are within the stipulated standard range, while location DD and UMD are above the stipulated standard. The calculated LPI in the four locations is shown in tables 1 and 2. Table 3 presented the standard of the characteristics and LPI of the leachate pollutant, with an estimated value of 7.378. Total coliform and total iron were not used for the computation because they have no standard (Kumar and Alapat, 2003).

Table 1: Characteristics and LPI of leachate from OD and ID

		Value		Sub-index value		Variable weight		Overall pollutant rating		Standard variable weight	Standard pollutant Rating
S/N	Parameters	OD	ID	OD	ID	OD	ID	OD	ID		
	Cr	0.04	0.02	5	5	0.064	0.064	0.32	0.32	0.064	0.58
	Pb	0.01	0.01	5	5	0.063	0.063	0.315	0.315	0.063	0.32
	pH	6.70	6.80	5	5	0.055	0.055	0.275	0.374	0.055	0.28
	TDS	38.41	42.10	86	92	0.050	0.050	4.3	4.6	0.050	0.35
	BOD	1.20	2.80	5	6	0.061	0.061	0.305	0.366	0.061	0.37
	COD	10.40	14.21	5	6	0.062	0.062	0.31	0.372	0.062	0.62
	NH_3-N	0.98	1.31	5	5	0.051	0.051	0.255	0.255	0.051	0.36
	Fe	0.02	0.04	5	5	0.045	0.045	0.255	0.255	-	-
	Cyanide	0.8	0.1	9	5	0.058	0.058	0.522	0.29	0.058	0.35
	TKN	0.10	0.09	5	5	0.053	0.053	0.265	0.265	0.053	0.32
	Zn	0.16	0.12	5	5	0.056	0.056	0.28	0.28	0.056	0.34
	N_i	ND	0.03	-	5	-	0.052	-	0.26	0.052	0.52
	Hg	ND	ND	-	-	-	-	-	-	0.062	0.37
	As	ND	0.01	-	5	-	0.061	-	0.305	0.061	0.31
	Phenol	0.84	1.07	5	5	0.057	0.057	0.285	0.285	0.057	0.29
	Cl	9.40	10.40	5	5	0.049	0.049	0.245	0.245	0.049	0.39
	Cu	0.02	0.02	5	5	0.050	0.050	0.25	0.25	0.050	0.90
	TC	4	-	10	-	0.052	-	0.52	-	-	-
	TOTAL					0.721	0.776	8.622	8.785	0.904	6.67
	LPI							11.95	11.32		7.378

Note: *All values are in mg/L except pH and Tc;Tc means total coliform (CFU/mL)*

Table 2: Characteristics and LPI of leachate from DD and UMD

		Value		Sub-index value		Variable weight		Overall pollutant rating		Standard variable weight	Standard pollutant Rating
S/N	Parameters	DD	UMD	DD	UMD	DD	UMD	DD	UMD		
	Cr	0.02	0.025	5	5	0.064	0.064	0.32	0.32	0.064	0.58
	Pb	0.02	0.02	5	5	0.063	0.063	0.315	0.315	0.063	0.32
	pH	7.10	6.60	5	5	0.055	0.055	0.275	0.275	0.055	0.28
	TDS	29.80	37.07	65	84	0.050	0.050	3.25	4.2	0.050	0.35
	BOD	1.90	1.80	5	5	0.061	0.061	0.305	0.305	0.061	0.37
	COD	16.30	18.00	5	6	0.062	0.062	0.31	0.372	0.062	0.62
	NH_3-N	2.03	2.09	5	5	0.051	0.051	0.255	0.255	0.051	0.36
	Fe	0.07	0.09	5	5	0.045	0.045	0.255	0.255	-	-
	Cyanide	0.10	0.17	5	5	0.058	0.058	0.29	0.29	0.058	0.35
	TKN	0.21	0.16	5	5	0.053	0.053	0.265	0.265	0.053	0.32
	Zn	0.168	0.21	5	5	0.056	0.056	0.28	0.28	0.056	0.34
	N_i	0.07	0.09	5	5	0.052	0.052	0.26	0.26	0.052	0.52
	Hg	ND	ND	-	-	-		-	-	0.062	0.37
	As	ND	0.04	-	5	-	0.061	-	0.305	0.061	0.31
	Phenol	2.80	3.00	5	6	0.057	0.057	0.285	0.342	0.057	0.29
	Cl	7.06	11.00	5	5	0.049	0.049	0.245	0.245	0.049	0.39
	Cu	0.04	0.06	5	5	0.050	0.050	0.25	0.25	0.050	0.90
	TC	2	5	6	10	0.052	0.52	0.312	0.52	-	-
	TOTAL					0.878	0.887	7.437	8.937	0.904	6.67
	LPI							8.47	10.08		7.378

Note: *All values are in mg/L except pH and Tc;Tc means total coliform (CFU/mL)*

Table 3: Leachate pollution index standard

S/N	Parameters	Leachate disposal standard	Sub index value	Variable weight	Overall pollutant rating
1	Cr	2.0	9	0.064	0.58
2	Pb	0.1	5	0.063	0.32
3	COD	250	10	0.062	0.62
4	Hg	0.01	6	0.062	0.37
5	BOD	30	6	0.061	0.37
6	As	0.20	5	0.001	0.31
7	Cyanide	0.2	6	0.058	0.35
8	Phenol	1.0	5	0.057	0.29
9	Zn	5.0	6	0.056	0.34
10	pH	5.5-9.0	5	0.055	0.28
11	TKN	100	6	0.053	0.32
12	Ni	3.0	10	0.052	0.52
13	Tc	No standard	-	0.052	-
14	NH_3-N	50	7	0.051	0.36
15	TDS	2100	7	0.050	0.35
16	Cu	3.0	18	0.050	0.90
17	Cl	100	8	0.049	0.39
18	Total Iron	No standard	-	0.045	-
	Total				6.67
	LPI				7.378

Comparing the results of the individual dumpsites with the standard in table 3, it is observed that chromium, lead, BOD, COD, arsenic, zinc, TKN, nickel, NH-N, TDS, copper and chloride fell below the standard. Also, the pH values for all the dumpsites investigated are within the stipulated range. For cyanide, OD was found to be above the stipulated standard having pollution rating of 0.522. For phenol OD and ID are within the stipulated standard range, while DD and UMD are above the stipulated standard. The values for lead in all the four sites was found to be very close to the standard rating, having pollution rating of 0.315. Total iron and total coliform have no stipulated standard which makes them difficult for comparison with the standard. A graphical representation of LPI values for each landfill site is presented in figure 2. The LPI values for all the dumpsites investigated were above the standard of 7.378. This is an indication that the leachates from each of the dumpsites have the capacity to contaminate the groundwater within the vicinity of the dumpsites. However, the risk is higher with OD and DD.Spearman's rank correlation coefficients have also been computed to examine the possible relationships among the various measured parameters (Table 4). High positive correlation was found between COD and Zn,; phenol and total coliform; and arsenic and zinc. This is an indication of their contribution to the groundwater mineralisation and contamination. Also, strong correlation between Cu and Cl; and Zn and Cl indicate that they must have originated from the same source. With the unconfined nature of the aquifer system in the area, and static water level of 0.2 - 4 m (Ohwoghere –Asuma and Adaikpoh, 2013), there is an urgent need for Local Authority and Government to swing into clean up and remediation action to avoid an outbreak of water - borne associated diseases in the area.

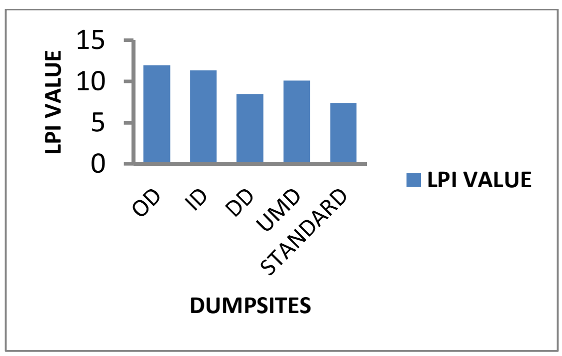

Fig 2: Chart showing the dumpsites LPI values

Table 4: Spearman Rank - order correlation coefficient of the different LPI parameters

	Cr	Pb	COD	Hg	BOD	As	Cyanide	Phenol	Zinc	pH	TKN	Ni	NH_3N	TDS	Cu	Cl	Total Fe	Total Coliform
Cr	1																	
Pb	.000	1																
COD	-.185	.855	1															
Hg	-.577	-.577	-.107	1														
BOD	-.192	.942	.974	-.274	1													
As	.457	.457	.676	-.088	.553	1												
Cyanide	.366	.658	.814	-.211	.731	.970	1											
Phenol	-.008	.994	.904	-.506	.968	.535	.724	1										
Zinc	.535	.841	.583	-.839	.669	.571	.699	.824	1									
pH	-.802	.267	.118	.000	.258	-.652	-.469	.213	-.164	1								
TKN	-.206	.928	.682	-.595	.829	.094	.332	.890	.694	.579	1							
Ni	-.072	.931	.983	-.289	.989	.666	.822	.965	.717	.115	.768	1						
NH_3N	-.143	.968	.954	-.357	.996	.535	.721	.986	.722	.263	.864	.985	1					
TDS	.200	-.764	-.393	.679	-.589	.210	-.025	-.693	-.582	-.693	-.940	-.506	-.641	1				
Cu	.302	.905	.864	-.522	.877	.782	.904	.930	.899	-.161	.684	.928	.895	-.445	1			
Cl	.489	-.290	.060	.360	-.141	.719	.530	-.201	.405	-.910	-.624	-.010	-.181	.824	.434	1		
Total Fe	.000	.928	.974	-.322	.977	.708	.856	.964	.753	.050	.747	.997	.975	-.481	.952	.036	1	
Total Coliform	.612	-.546	-.857	-.368	-.789	-.406	-.512	.610	-.088	-.331	-.456	-.757	-.734	.188	-.482	-.013	-.720	1

Conclusion: Water samples in and around the major dumpsites in Ughelli were collected and analysed for parameters to determine the Leachate Pollution Index (LPI). The LPI values were far above the stipulated standard and this indicates that the leachate generated are contaminated and has impacted on the environment, and the quality of groundwater in the area. It is therefore recommended that continuous dumping of waste in the area should be discouraged and proper evacuation and clean - up program be put in place.

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REFERENCES

Allen, JRL (1965) Late Quaternary Niger Delta and Adjacent Areas: Sedimentary Environments and Lithofacies. Bulletin American Association of Petroleum Geology vol. 49(5), 547–600.

Al-Khaldi, S (2006) Assessment of groundwater contamination vulnerability in the vicinity of Abqaiq landfill- A GIS Approach", King Fahd University of Petroleum and Minerals, Saudi Arabia.

American Public Health Association (APHA), (1998).Standard methods for the examination of water and wastewater, 20th ed. Clesceri LS, Greenberg AE, & Eaton, AD, (Eds); American Public Health Association: Washington, DC. 1325p

American Public Health Association APHA (1985) Standard methods for the examination of water and waste water. American Public Health Association, Washington D. C, U.S.A, revised Ed, 635pp

Abbas, AA; Jingsong, G; Ping, LZ; Ya, P Y; Al - Rekabi, WS (2009) Review on landfill leachate treatments. Journal of Applied Science Research. 5(5), 534 - 545

Barjinder B; Saini, MS; Jha, MK(2014).Assessment of Municipal Solid Waste Landfill Leachate Treatment Efficiency by Leachate Pollution Index.International Journal of Innovative Research in Science, Engineering and Technology. 3(1),8448-8454.

Chain, ESK; DeWalle, FB.(1976) Sanitary landfill leachates and their treatment.ASCE.Journal of Environmental Engineering Division.102(2):411.

Deng, Y; Englehardt, JD (2007) Electrochemical oxidation for landfill leachate treatment. Waste Management. 27(3) 380 - 388.

D'Souza, O; Somashekar, RK (2012) Pollution Potential of Leachate from an Unscientific Landfill and Its Impact on Groundwater.Electronic Journal of Environmental Science, **5**, 21-32.

Egbai JC;Adaikpoh, EO;Aigbogun, CO(2013): Water Quality Assessment of Groundwater In Okwuagbe Community Of Delta State Nigeria. Technical Journal of Engineering and Applied Sciences (TJEAS) 3 (19): 2347-2356.

Fatta, D; Papadopoulos, A;Loizidou, M. (1999) A study on the landfill leachate and its impact on the groundwater quality of Greater Area", Environ. Geochem. Health, pp. 175-190.

Fronczyk, J; Garbulewski, K (2009) "Selection of material suitable for permeable reactive barriers in the vicinity of landfills," Department of Geotechnical Engineering, Warsaw University of Life Sciences, Land Reclamation, Vol. 41, pp. 3-9.

Kelley, WE (1976) Groundwater pollution near a landfill.ASCE. Journal of Environmental Engineering Division.102(6):1189.

Kouzeli-Katsiri A; Bodogianni A; Christoulas D (1999) Prediction of leachate quality from sanitary landfills. Journal of Environmental Engineering Division, ASCE.125:950–957.

Kumar D; Alappat BJ (2003) Analysis of leachate contamination potential of a municipal landfill using leachate pollution index.Workshop on sustainable landfill management, India.3-5:147-153.

Kumar, D; Alappat, BJ. (2003) A technique to quantify landfill leachate pollution", In: Proceedings of the Ninth International Landfill Symposium, Cagliari, Italy, Paper no.400.

Leckie, JO; Pacey, JG; Halvadak, C (1979) Landfill management with moisture control. Journal of Environmental Engineering Division, American Society of Civil Engineering (ASCE)1051:337–355.

Lee, GF; Jones-Lee, A (2004) Landfilling of Municipal Solid Waste", Report of G.F Lee and Associates, El Macero, CA.

Longe EO; Balogun, MR (2010) Groundwater quality assessment near a municipal landfill, Lagos, Nigeria.Research Journal of Applied Science, Engineering and Technology.2(1):39-44.

Mohajeri, S; Aziz, HA; Isa, H; Zahed, MA; Adlan MN. (2010) Statistical optimization of process parameters for land fill leachate treatment using electro-fenton technique. Journal of Hazardous Materials.176(3):749–758.

Mohammad, U; Hamidi, A; Mohd, SY (2010) Variability of Parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia.International Journal of Chemical Engineering.DOI.1155/2010/747953.

Ofomola, MO; Ako, BD; Adelusi, AO (2016) Flow direction and velocity determination of dumpsite-induced groundwater contamination in part of Delta State, Nigeria. Arabian Journal of Geosciences 9(5) 1-12. DOI 10.1007/s12517-016-2405-y

Ohwoghere-Asuma, O; Adaikpoh, EO (2013)Assessment of Shallow Aquifers Contamination by Failure of on-Site Sewage Disposal System in Ughelli, Western Niger Delta, Nigeria. Journal of Environment and Earth Science. 3(9): 208 - 216

Rafizul, IM; Alamgir, M; Kraft, E; Haedrich, G (2011) Bio-treatment of leachate generated from municipal solid waste in sanitary landfill lysimeter. 2nd International conference on solid waste management in developing Asian countries, KUEST, Bangladesh.191–193.

Reinhart, DR; Grosh, CJ (1994) Analysis of Florida MSW landfill leachate quality.Department of Civil and Environmental Engineering, University of Central Florida.

Reyment, RA (1965) Aspects of the Geology of Nigeria. University of Ibadan Press, Ibadan. 132pp

Salami L; Fadayini O; Patinvoh R.J; Koleola O.(2015).Evaluation of Leachate Contamination Potential of Lagos Dumpsites Using Leachate Pollution Index.British Journal of Applied Science & Technology,5(1): 48-59.

Short, KC; Stauble, AJ (1967) Outline of the Niger Delta.Bulletin American Association Petroleum Geology., 54 (5), 761-779.

Susu, AA; Salami, L (2011) Proposal for joint research efforts with the Ministry of Environment on surface and ground water contamination and remediation near municipal landfill site, Lagos, Nigeria. 1–2.

United States Environmental Protection Agency (USEPA) (1984) Office of Drinking Water, A Groundwater Protection Strategy for the Environmental Protection Agency.

Weber, KJ; Daukuro E.(1975) Petroleum Geology of the Niger Delta. Proceedings of 9th Petroleum congress Tokyo, 209 – 229